Prediction of Aeroelastic Stability Using Computational Fluid Dynamics

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Report Documentation Page

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UAV Context

- Control system and flexibility integrated
- High rate motions
- Unusual design – unusual aerodynamics (B2 residual pitch problem)

➢ Places strain on linear aeroelastic methods

  ➢ RANS based tools needed

Holy Grail of Non-linear Aeroelasticity

- Diminish/remove unfavourable effects
  - LCO even a stable one has fatigue issues
  - Control system interactions (buzz?)
- Increase/exploit favourable effects
- Move from analysis into design
  - Non conservative designs
  - Possible higher performance

Fluid Structure Interaction

- Model the time dependent aerodynamics
- Model the deforming structure under load
- Match the aerodynamics loads + structural deformations in time
- Transfer the loads + displacements information

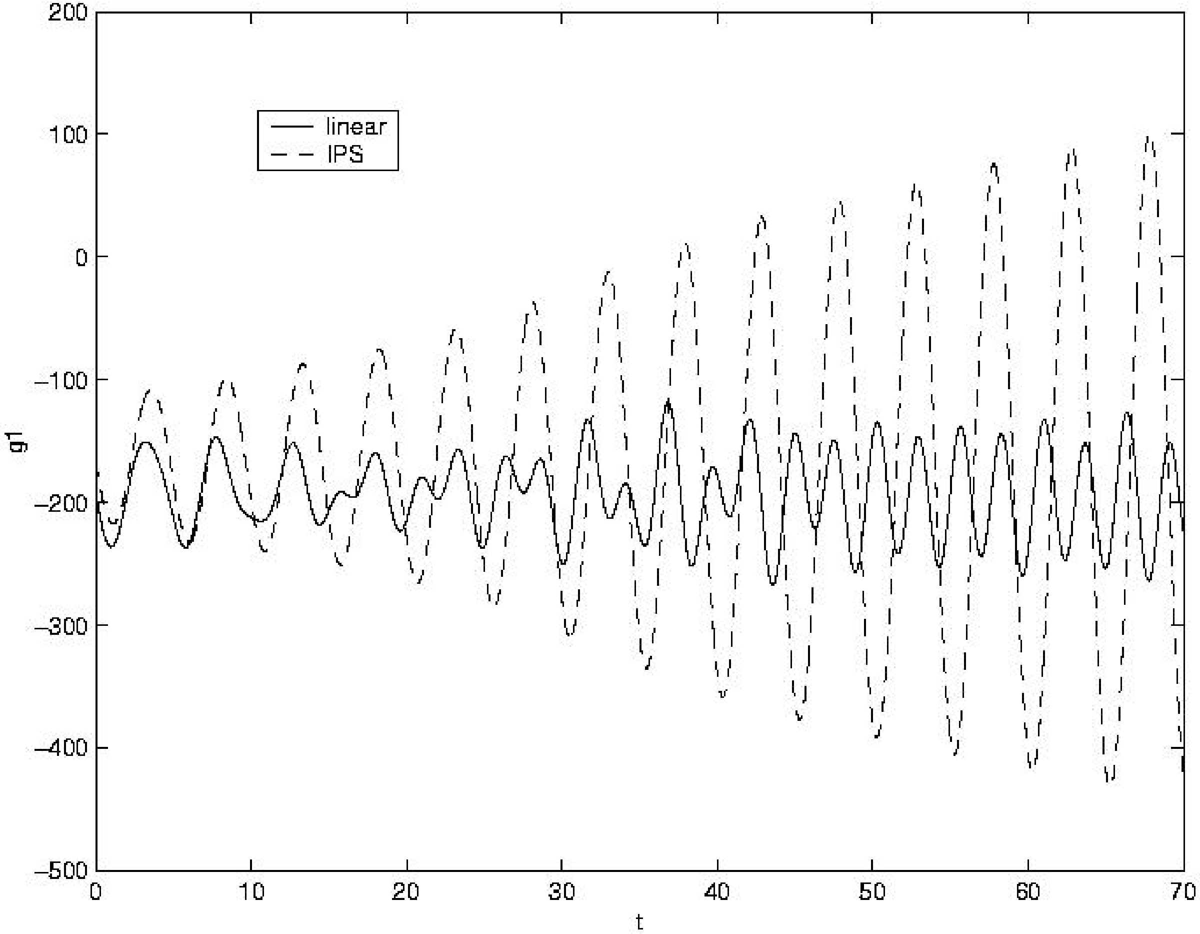
Aerodynamic Model Requirements

- RANS needed to capture large scale features
  - Still expensive, textbook MG required?
  - Validation of vortical flows
  - Prediction of flow separation (onset and progression)
  - Reduction via POD or ROM
- Small geometric features important
  - Vg’s and riblets (hybrid / unstructured?)
- Active control requirements
  - Fully understand unsteady flows
  - Multi-disciplinary process

Time Domain Simulation

- CFD-CSD model sequencing resolved
  - Staggered schemes, sub-iterations
- Inter-grid transformation can be a problem
  - CVT method is simple and effective, other methods can alter the dynamics
  - “Knowledge” based transformations. Total force and moment conservation + geometric constraints
  - Depends on structural model (Stick models)
- Volume grid deformation resolved
  - TFI, springs…

MDO Test Case – Influence of Transformation

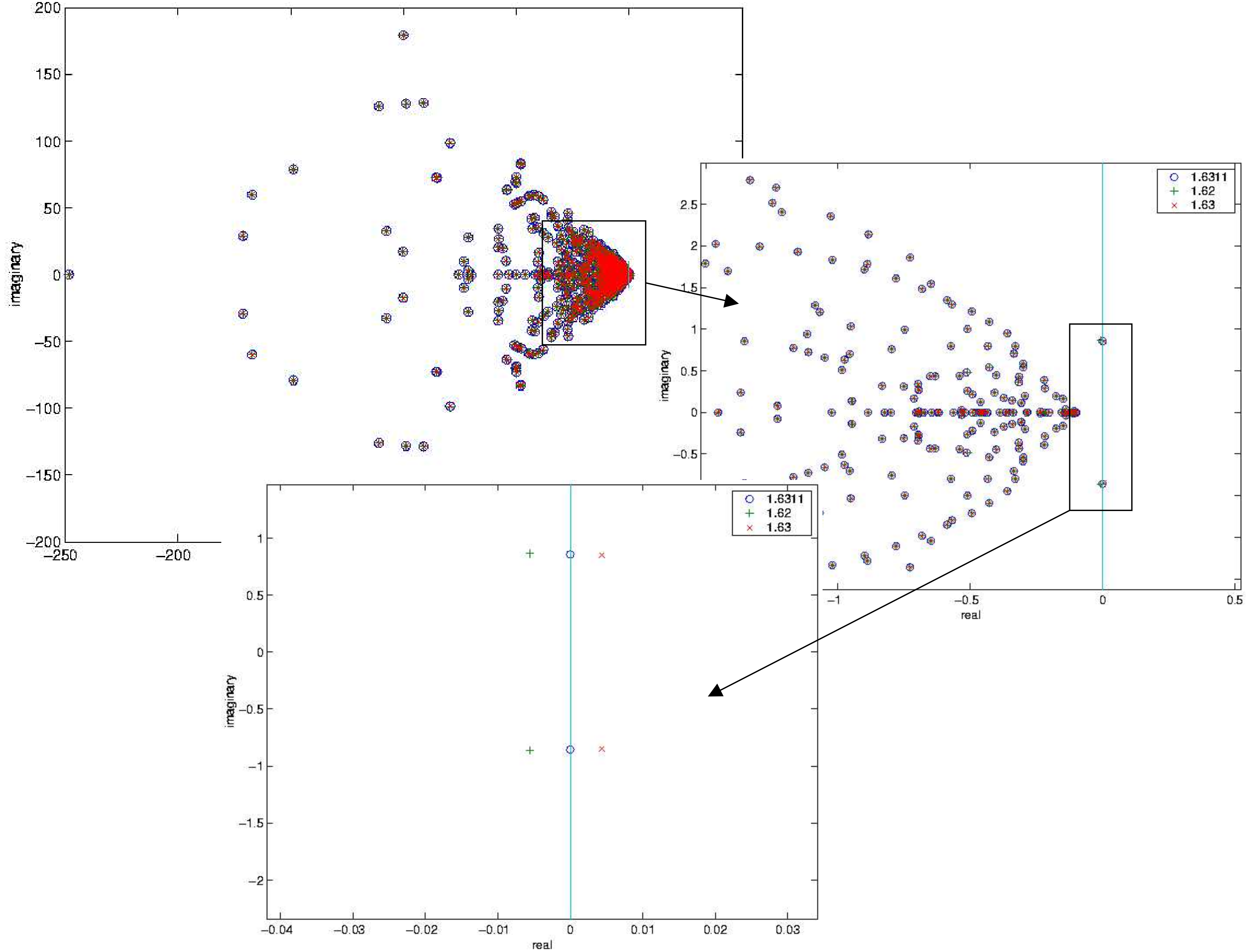


Conclusion on Time Marching

- Predictions of vortical flow effects need to be validated
- Transformation between grids needs care
- Calculations are costly
  - Suitable for analysis of isolated points
  - Unsuitable for design and certification

Direct Calculation

- Unfavourable effects can be described mathematically
  - LCO is a Hopf bifurcation
- Add these conditions in the system of ODE's
  - This system is larger and much harder to solve
  - Only have to solve it once
  - Can play all sorts of steady CFD tricks
- Can only pick one type at a time
- What does non convergence mean?



imaginary
real
1.6311
1.62
1.63

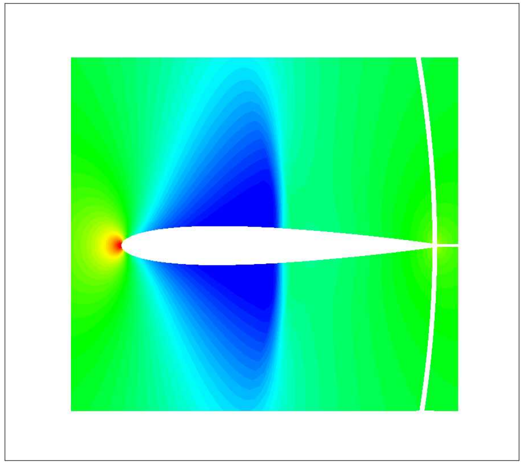
Solution of Augmented System

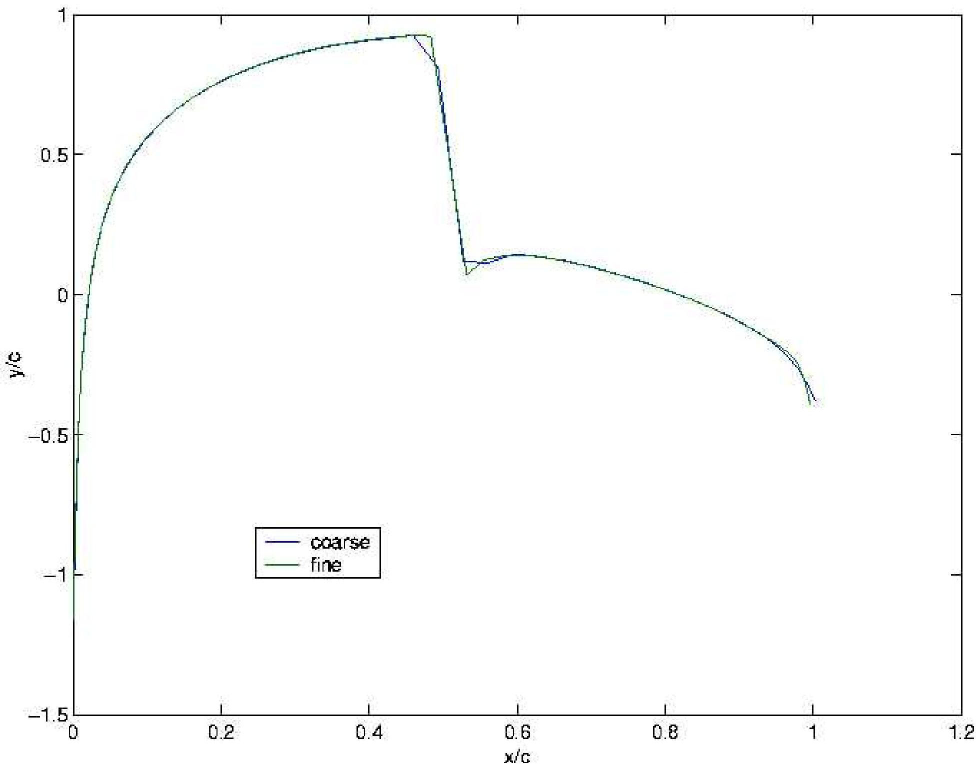
$$
\begin{bmatrix}
A & 0 & 0 & \mathbf{R}_\mu & 0 \\
(A\mathbf{P}_1)_w & A & I\omega & (A\mathbf{P}_1)_\mu & -\mathbf{P}_2 \\
(A\mathbf{P}_2)_w & -I\omega & A & (A\mathbf{P}_2)_\mu & \mathbf{P}_1 \\
0 & \mathbf{S}^T & 0 & 0 & 0 \\
0 & 0 & \mathbf{S}^T & 0 & 0
\end{bmatrix}
\times \Delta
\begin{bmatrix}
\mathbf{w} \\ \mathbf{P}_1 \\ \mathbf{P}_2 \\ \mu \\ \omega
\end{bmatrix}
= -
\begin{bmatrix}
\mathbf{R} \\
A\mathbf{P}_1 + \omega\mathbf{P}_2 \\
A\mathbf{P}_2 - \omega\mathbf{P}_1 \\
\mathbf{S}^T\mathbf{P}_1 \\
\mathbf{S}^T\mathbf{P}_2 - 1
\end{bmatrix}
$$

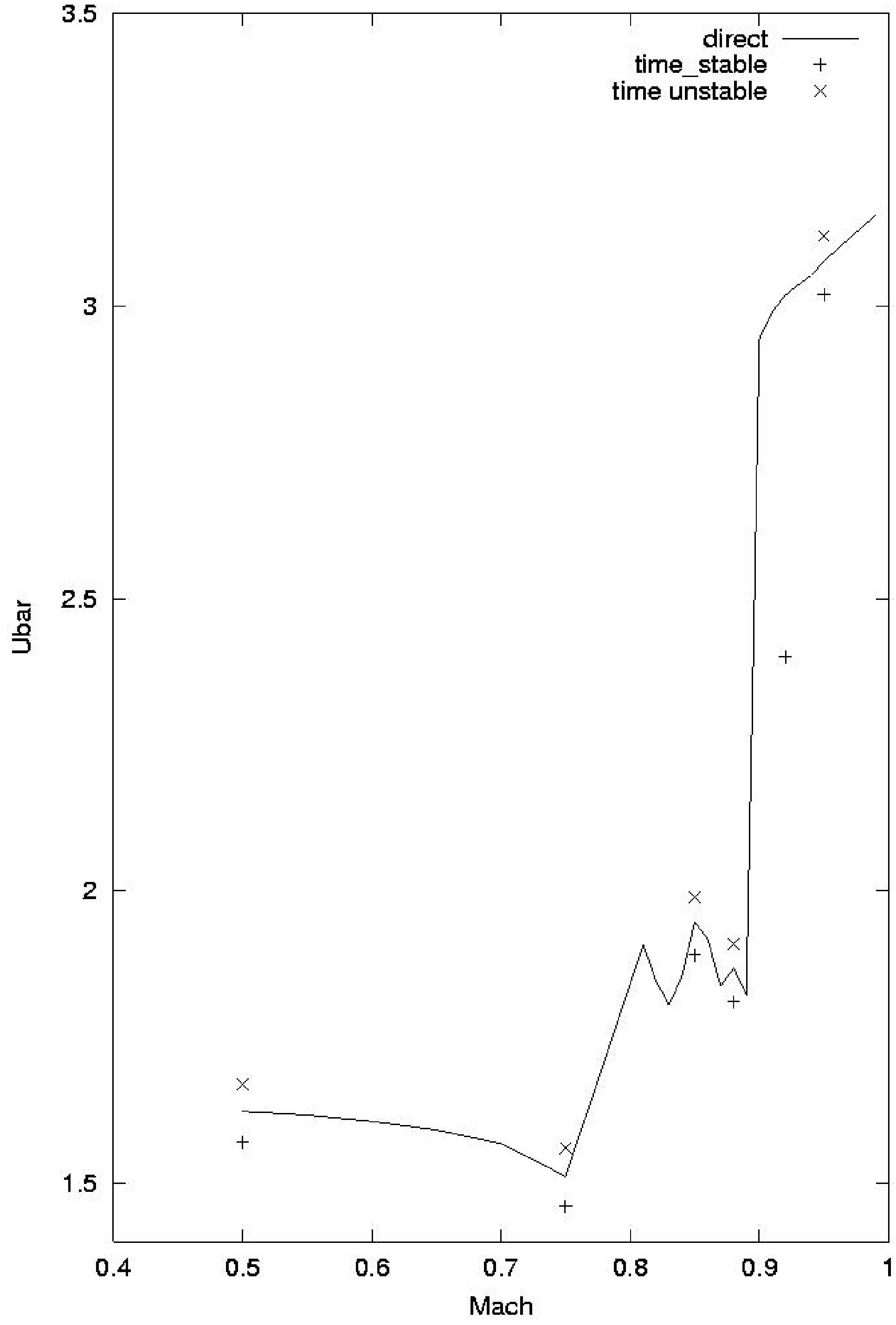
Symmetric problem

Results

- NACA0012 aerofoil
- C-grid, 128x32







direct
time_stable
time unstable
3.5
3
2.5
2
1.5
Ubar
0.4
0.5
0.6
0.7
0.8
0.9
1
Mach

Evaluation

- Cost
  - Complete boundary in 2700s
  - Time marching calculation >5600s per point
  - Linear solver needs work
    - Preconditioner
    - Optimise code
- Generality
  - Build in equilibrium calculation as outer loop
  - Build in flight mechanics equations (PUMA)

Conclusions

- Efficient tools with right level of modelling needed for fully integrated design of unusual vehicles
- Time marching developing towards useful tool for simulation of problematic conditions
- Tools (maybe direct method) needed for general design and certification purposes
- Could we limit the physical modelling in some regions of the design space to make current tools applicable now?
- Methods need to integrate all sources of data into model

Outlook

- How valid are statements of stability based on modal damping?
- How do we integrate measurements and predictions in manner required at the moment?
- If high fidelity simulation is available in what ways will this influence the designs?